TUNABLE CLOCK DISTRIBUTION SYSTEM FOR REDUCING POWER DISSIPATION

FIELD OF THE INVENTION

[0001]   The present invention relates to integrated circuits using clock signals. More specifically, the present invention relates to tunable clock distribution circuits for reducing the power dissipation of a clock distribution network.

BACKGROUND OF THE INVENTION

[0002]   Synchronous integrated circuits (IC) rely on one or more clock signals to synchronize elements across the integrated circuit. Typically, one or more clock signals are distributed across the system on one or more clock distribution networks. Fig. 1 illustrates a typical synchronous IC 100, which can be for example, a microprocessor, a programmable logic device (PLD) such as a field programmable gate array (FPGA), a digital signal processor, or a graphics controller. Specifically, synchronous IC 100 has a clock generating circuit 110, a clock driver 120, and a clock distribution network 130, and logic blocks 140, 150, 160, and 170. Specifically, clock generating circuit 110 drives a clock signal CLK to clock driver 120. In some integrated circuits, clock signal CLK is provided from an external clock generating circuit. Clock driver 120 amplifies clock signal CLK to drive a system clock signal S_CLK to logic blocks 140-170 on clock distribution network 130. Logic blocks 140-170 perform various logic functions using system clock signal S_CLK.

[0003]   A common way to increase the performance of synchronous IC 100 is to increase the frequency of system clock signal S_CLK (and clock signal CLK) on clock distribution network 130. If logic blocks 140-170 can accommodate an increased clock frequency, the performance of

integrated circuit 100 is directly proportional to the clock
frequency. Thus, doubling of the frequency of system clock
signal S_CLK doubles the performance of synchronous IC 100.
[0004]   However, increasing the frequency of clock signal
S_CLK greatly increases the power consumption of synchronous
IC 100. As shown in equation (1), P_f the frequency dependent
component of the power, dissipated by clock distribution
network 130 is equal to the capacitance C_net on clock
distribution network 130 multiplied by the square of the
voltage swing between logic low (typically 0) and logic high
(typically V) multiplied by the frequency F of system clock
signal S_CLK.

$$P_f = C\_net * V^2 * F \qquad\qquad (1)$$

[0005]   Power dissipation in integrated circuits is
typically in the form of heat. Excess heat may damage
integrated circuits, thus additional costly cooling systems
may be required for a high frequency integrated circuit.
Furthermore, many integrated circuits are used in portable
systems, such as laptop computers, which have limited battery
life. To extend the battery life of portable systems,
integrated circuit must minimize power dissipation. Thus,
there is a need for a circuit or a method to minimize power
dissipation on high frequency clock distribution networks in
integrated circuits.

SUMMARY

[0006]   The present invention provides a tunable clock
distribution system with an adjustable resonant frequency in
an integrated circuit which is tuned towards the frequency of
the clock signal on a clock distribution network. As the
resonant frequency of the tunable clock distribution system
approaches the clock frequency of the clock signal, the power
dissipation of the clock distribution network decreases. By
matching the resonant frequency of the tunable clock

distribution system with the frequency of the clock signal on the clock distribution network, power dissipation of the clock distribution network is minimized.

[0007] An exemplary embodiment of the present invention provides an integrated circuit having: a clock distribution network; and an inductance control circuit coupled to the clock distribution network and receiving a clock signal, where the inductance control circuit, having an inductance, is configured to provide a resonant frequency of the clock distribution network as a function of a clock frequency of the clock signal.

[0008] In accordance with another embodiment of the present invention, the tunable clock distribution system includes an inductance control circuit. The inductance control circuit includes multiple controllable inductance circuits. Each controllable inductance circuit includes an inductor coupled to the clock distribution network, a switchable bypass circuit coupled in parallel with the inductor, and a control circuit for the switchable bypass circuit. A controllable inductance circuit is activated to add inductance to the clock distribution network by switching the switchable bypass circuit to a non-conductive state. Conversely, a controllable inductance circuit is deactivated to not add inductance to the clock distribution network by switching the switchable bypass circuit to conductive state.

[0009] In some embodiments of the present invention, the tunable clock distribution system includes one or more capacitance control circuits coupled between the clock distribution network and ground. In a specific embodiment of the capacitance control circuit, a capacitor and pass gate are coupled in series between the clock distribution network and ground. A pass gate control circuit, such as a configuration memory cell, controls the pass gate. To add capacitance to the clock distribution network, the pass gate is switched to a conductive state. By controlling the capacitance and inductance of the clock distribution network,

the resonant frequency of the tunable clock distribution system can be closely matched to the frequency of the clock signal on the clock distribution network. A close matching between the resonant frequency of the tunable clock distribution system and the frequency of the clock signal results in lower power dissipation by the clock distribution network. The present invention will be more fully understood in view of the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]   Figure 1 is a block diagram of an integrated circuit using a conventional clock distribution network.

[0011]   Figure 2 is a block diagram of a tunable clock distribution circuit in accordance with one embodiment of the present invention.

[0012]   Figure 2-1 is a block diagram of a tunable clock distribution circuit in accordance with a second embodiment of the present invention.

[0013]   Figure 3(a) is a schematic diagram of an inductance control circuit in accordance with one embodiment of the present invention.

[0014]   Figure 3(b) is a schematic diagram of multiple inductance control circuits in accordance with one embodiment of the present invention.

[0015]   Figures 4(a) is a schematic diagram of a capacitance control circuit in accordance with one embodiment of the present invention.

[0016]   Figure 4(b) is a schematic diagram of multiple capacitance control circuits in accordance with one embodiment of the present invention.

[0017]   Figure 5 is a schematic diagram of a tunable clock distribution system of an alternative embodiment of the present invention.

DETAILED DESCRIPTION

[0018]   Figure 2 is a block diagram of a tunable clock distribution system 200 in accordance with one embodiment of the present invention.   Tunable clock distribution circuit 200 is coupled to clock driver 120 which is coupled to clock generating circuit 110.   Tunable clock distribution circuit 200 includes clock distribution network 230, an inductance control circuit 210 and an optional capacitance control circuit 220.   Specifically, clock driver 120 drives system clock signal S_CLK through inductance control circuit 210 onto a clock distribution network 230, where clock distribution network 230 distributes a clock signal (L_CLK) to logic blocks 140 -170, that may be part of a FPGA.   For clarity, the clock signal on clock distribution network 230 after inductance control circuit 210 is referred to as inducted clock signal L_CLK.   Optional capacitance control circuit 220 is coupled between clock distribution network 230 and ground.

[0019]   Inductance control circuit 210 is configured to adjust the combined impedance of tunable clock distribution system 200, i.e. the impedance of inductance control circuit 210, clock distribution network 230, and capacitance control circuit 220.   Specifically, inductance control circuit 210 adds a tunable inductance L_tune on clock distribution network 230.   By adding tunable inductance L_tune on clock distribution network 230, tunable clock distribution system 200 has a resonant frequency F_r as explained below.   Tunable inductance L_tune adjusts resonant frequency F_r of tunable clock distribution system 200 to equal the clock frequency F_clk of system clock signal S_CLK.   Clock frequency F_clk of system clock signal S_CLK is the same as the frequency of inducted clock signal L_CLK.   Capacitance control circuit 220, which may be included in some embodiments of the present invention, also adjusts the impedance of tunable clock distribution system 200 by adding a tunable capacitance C_tune to clock distribution network 230.   Specifically,

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tunable capacitance C_tune is used to adjust resonant
frequency F_r of tunable clock distribution system 200 to
equal the clock frequency F_clk of system clock signal S_CLK.

[0020]   Figure 2-1 is a block diagram of a tunable clock
distribution circuit 200' in accordance with a second
embodiment of the present invention. Figure 2-1 is similar
to Figure 2 and the same labels are used were the blocks are
the same. Inductance control circuit 210' includes a
variable or adjustable inductance and is connected between
S_CLK and L_CLK. Capacitance control circuit 220' has a
variable or adjustable capacitor and is connected between
L_CLK and ground. Hence the variable or adjustable inductor
and/or capacitor form a tunable LC circuit which may be used
to adjust the resonant frequency of clock distribution
network 230 to match, for example, the frequency of S_CLK.

[0021]   With reference back to Figure 2, by including
inductance control circuit 210 and capacitance control
circuit 220, tunable clock distribution system 200, like
clock distribution system 200' in Figure 2-1, behaves like a
resistive/inductive/capacitive (RLC) circuit. Specifically,
the inherent resistance of clock distribution network 230 is
the equivalent resistance R of the RLC circuit. The
inductance of clock distribution network 230 combined with
the additional inductance (i.e., inductance L_tune) provided
by inductance control circuit 210 is the equivalent
inductance L of the RLC circuit and the capacitance of clock
distribution network 230 combined with the additional
capacitance provided by capacitance control circuit 220 (i.e.
tunable capacitance C_tune) is the equivalent capacitance C
of the RLC circuit. For clarity, the total capacitance on
clock distribution network 230 is referred to as capacitance
C_net.

[0022]   As shown in equation (2), the resonant frequency
F_r of a RLC circuit is equal to one over 2 times • times the
square root of the inductance L multiplied by the capacitance
C of the RLC circuit, i.e.:

$$F\_r = 1/2\pi\sqrt{LC} \qquad\qquad (2)$$

[0023]   As shown in equation (3), when an RLC circuit is driven at the resonant frequency of the RLC circuit, the power dissipation of the RLC circuit is equal to the integral over time of the absolute value of the current I in the inductor of the RLC circuit multiplied by the resistance R of the RLC circuit, which is equal to the current I multiplied by the square of the resistance R.

$$P = \int|IR|\partial t = IR^2 \qquad\qquad (3)$$

[0024]   Thus, in an RLC circuit driven at the resonant frequency F_r of the RLC circuit, the power dissipated does not depend on the frequency or the capacitance of the RLC circuit.

[0025]   Thus, the power dissipation of clock distribution network 230 can be minimized by configuring inductance control circuit 210 and capacitance control circuit 220 so that resonant frequency F_r of tunable clock distribution system 200 is equal to clock frequency F_clk of system clock signal S_CLK. In general, the power dissipated by clock distribution network 230 decreases as resonant frequency F_r of tunable clock distribution system 200 is adjusted towards clock frequency F_clk of system clock signal S_CLK. Power dissipation is minimized if a perfect match of resonant frequency F_r of tunable clock distribution system 200 with clock frequency F_clk of system clock signal S_CLK is achieved. Because resonant frequency F_r is dependent equivalently on both tunable inductance L_tune and network capacitance C_net of clock distribution network 230, many embodiments of the present invention do not include capacitance control circuit 220. These embodiments instead rely on the capacitance caused by the coupling of clock

distribution network 230 to various logic blocks, such as
logic blocks 140-170 of Fig. 1.

[0026] Many integrated circuits are designed and
manufactured for use at a specific frequency. For these
integrated circuits, inductance control circuit 210 can be an
inductor 306 (Fig. 3(a)) having a fixed inductance L_match.
Thus, tunable inductance L_tune is equal to inductance
L_match. The value of inductance L_match can be determined
using equation (3).

$$L\_match = \frac{1}{\left(2\pi F\_clk\right)^2 C\_net} \tag{3}$$

[0027] Specifically L_match is equal to 1 divided by
network capacitance C_net multiplied by the square of 2 times
• times clock frequency F_clk of system clock signal S_CLK.
For integrated circuits with fixed routing and
configurations, capacitance C_net of clock distribution
network 230 can be calculated using conventional design and
layout tools. While process variations may cause capacitance
C_net of clock distribution network 230 to vary between
different instances of the integrated circuit, the resonant
frequency of tunable clock distribution system 200 is closer
to clock frequency F_clk of system clock signal S_CLK in an
instance of the integrated circuit including inductance
control circuit 210 than in instances of the integrated
circuit not using inductance control circuit 210. Therefore,
power dissipation in instances of an integrated circuit using
inductance control circuit 210 is less than the power
dissipation in instances of the integrated circuit not using
inductance control circuit 210.

[0028] Some integrated circuits may be used over a range
of frequencies. For example, instances of a FPGA may be used
by end users at many different clock frequencies.
Furthermore, some integrated circuits, such as FPGAs, are re-
configurable. Each configuration of the FPGA may cause
network capacitance C_net of clock distribution network 230

to change. For these integrated circuits, the inductance
provided by inductance control circuit 210 must change to
match the specific value of clock frequency F_clk and network
capacitance C_net in each instance of the integrated circuit.
Fig. 3(b) is a schematic diagram of an embodiment of multiple
inductance control circuits that can be tuned to provide
different values for tunable inductance L_tune.
Specifically, the embodiment of Fig. 3(b) comprises one or
more inductance control circuits 310_0 to 310_X, where X is a
positive integer. Inductance control circuit 310_0 has an
input terminal IN coupled to receive system clock signal
S_CLK. Inductance control circuit 310_X has an output
terminal OUT coupled to drive inducted clock signal L_CLK.
Each inductance control circuit 310_Y has an input terminal
IN coupled to an output terminal OUT of inductance control
circuit 310_(Y-1), where Y is an integer between 1 and X-1.
Each inductance control circuit 310_Y also has an output
terminal OUT coupled to input terminal IN of inductance
control circuit 310_(Y+1). Each inductance control circuit
310_Z can be individually activated to add an inductance L_Z
to clock distribution network 230 or deactivated to not add
inductance to clock distribution network 230. Thus, as
stated in equation (4), tunable inductance L_tune provided by
tunable clock distribution circuit 200 is the sum of the
inductances from the subset of inductance control circuits
310_Z, which are activated. In equation (4), A_i is equal to
one if inductance control circuits 310_i is activated,
otherwise A_i is equal to zero.

$$L\_tune = \sum_{i=0}^{X} A\_i * L\_i \qquad\qquad (4)$$

[0029]   In the embodiment of Fig. 3(b), each inductance
control circuit 310_Z, includes a pass gate control circuit
320_Z, a pass gate 330_Z, and an inductor 340_Z, where Z is
an integer between 0 and X, inclusive. Pass gate 330_Z and
inductor 340_Z are coupled in parallel between input terminal
IN and output terminal OUT of inductance control circuit

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310_Z. Pass gate 330_Z is controlled by pass gate control circuit 320_Z. If inductance control circuit 310_Z is activated, pass gate control circuit 320_Z switches pass gate 330_Z to a non-conductive state. Therefore, input terminal IN and output terminal OUT are coupled by only inductor 340_Z and thus inductance L_Z on clock distribution network 230. Conversely, if inductance control circuit 310_Z is deactivated, pass gate control circuit 320_Z switches pass gate 330_Z to a conductive state, which provides a very low impedance path between input terminal IN and output terminal OUT. The very low impedance path through pass gate 330 is in parallel with inductor 340_Z. Consequently, inductor 340_Z is bypassed and does not provide inductance onto clock distribution network 230. Thus, pass gate 330_Z acts as a switchable bypass circuit for inductor 340_Z. Other embodiments may use other circuits, such as switchable buffers and transmission gates, in place of pass gate 330_Z for the switchable bypass circuit. Also while inductance control circuits 310_0 to 320_X are shown as series connected in Figure 3(b), in other embodiments these inductance control circuits may be connected in parallel or series or any combination thereof.

[0030]   In yet another embodiment of the present invention, an FPGA has a single inductance control circuit 310_0 connecting system clock S_CLK to L_CLK. Pass Gate 330_0 is replaced with a CMOS transistor whose gate is connected to pass gate control circuit 320_0 and whose drain and source connect IN to OUT of inductance control 310_0. Pass gate control circuit 320_0 is a configuration memory cell that may be set to logic 0 or 1, when the FPGA is configured or re-configured. If the CMOS transistor is an NMOS transistor, and the configuration memory cell is set to 1, the inductor 340_0 is bypassed. If the configuration memory cell is set to 0, the inductor 340_0 adds inductance to the clock distribution network. In a variation to this embodiment, the

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pass_gate 330_0 is replaced by a tri-state buffer connected in series to an inverter. The control input into the tri-state buffer is connected to a configuration memory cell to control whether or not the inductor 340_0 is bypassed.

[0031]   In one embodiment of the present invention, inductance L_Z of each inductor 340_Z is equal to a base inductance value L_B. Thus, inductance control circuit 210 can provide a tunable inductance L_tune between 0 and X * L_B. In another embodiment of the present invention, each inductor 340_Z has an inductance value L_Z equal to a base inductance L_B multiplied by two to the power of Z (see equation (5)).

$$L\_Z = L\_B * 2^Z \qquad\qquad (5)$$

[0032]   For this embodiment, inductance control circuit 210 can provide a tunable inductance L_tune between 0 and L_B * $(2^{(X+1)} - 1)$. Thus, for example, by using seven inductors, inductance control circuit 210 can provide a tunable inductance between 0 and 127 times base inductance L_B. The necessary tunable inductance L_tune can be determined using the frequency F of system clock signal S_CLK and network capacitance C_net of clock distribution network 230, which can be determined using conventional design and routing tools. The value of base inductance L_B is determined by the frequency range and the capacitance range of the integrated circuit.

[0033]   Many conventional circuits can be used for pass gate control circuits 320_0-320_X. For example, in an FPGA each pass gate control circuit 320_Z can be a configuration memory cell. In some integrated circuits, pass gate control circuit 320_0-320_X can be memory cells, decoded memory cells, flip-flops, logic gates, fuses, anti-fuses, or external signals received from package pins.

[0034]   As explained above, some embodiments of tunable clock distribution circuit 200 include capacitance control circuit 220 (Fig. 2). Capacitance control circuit 220 is

used to increase network capacitance C_net on clock
distribution network 230. For clarity, tunable capacitance
C_tune refers to the capacitance provided by capacitance
control circuit 220, capacitance C_norm is the capacitance on
clock distribution network 230 without capacitance control
circuit 220, and network capacitance C_net refers to the
total capacitance on clock distribution network 230. Thus,
network capacitance C_net is equal to tunable capacitance
C_tune plus capacitance C_norm. Thus, equation (3) given
above is applicable to embodiments of the present invention
using capacitance control circuit 220. However, the presence
of capacitance control circuit 220 allows tuning of resonant
frequency F_r of tunable clock distribution system 200 using
both capacitive elements and inductive elements. Although
only one capacitance control circuit 220 is shown in Fig. 2,
some embodiments of the present invention use multiple
capacitance control circuits (see Fig. 4(b)). The multiple
capacitance control circuits can be distributed at multiple
points of clock distribution network 230. Also while
capacitance control circuits 410_0 to 410_X are shown as
connected in parallel in Figure 4(b), in other embodiments
these capacitance control circuits may be connected in
parallel or series or any combination thereof.

[0035]   Fig. 4(a) illustrates an embodiment of capacitance
control circuit 220 applicable for integrated circuits, which
are designed and manufactured for use at a specific
frequency. Specifically, a capacitor 406 having a fixed
capacitance C_match is coupled between clock distribution
network 230 and ground. The value of capacitance C_match,
which is equal to tunable capacitance C_tune, is selected so
that capacitance C_net satisfies equation (3).

[0036]   For integrated circuits, which may be used over a
range of frequencies or are re-configurable. Multiple
capacitance control circuits may be used to control
capacitance C_net of clock distribution network 230. As
illustrated in Fig. 4(b), capacitance control circuits 220_0

to 220_X are coupled to clock distribution network 230. Each
capacitance control circuit 220_Z can be activated to provide
a capacitance C_Z on clock distribution network 230 or
deactivated to provide no additional capacitance to clock
distribution network 230. Thus, as stated in equation (6),
tunable capacitance C_tune is the sum of the capacitances
from the subset of capacitance control circuits 220_Z, which
are activated. In equation (4), B_i is equal to one if
capacitance control circuit 210_i is activated; otherwise B_i
is equal to zero.

$$C\_tune = \sum_{i=0}^{X} B\_i * C\_i \qquad (6)$$

[0037]   Each capacitance control circuit 410_Z, includes a
pass gate control circuit 420_Z, a pass gate 430_Z, and a
capacitor 440_Z. Specifically, each pass gate 430_Z is
coupled between capacitor 440_Z and clock distribution
network 230. Each capacitor 440_Z is coupled between pass
gate 430_Z and ground. Pass gate control circuit 420_Z
controls pass gate 430_Z. If capacitance control circuit
420_Z is activated, pass gate control circuit·420_Z switches
pass gate 430_Z to a conductive state. Therefore, clock
distribution network 230 is coupled to ground through
capacitor 440_Z, which adds an additional capacitance C_Z to
clock distribution network 230. Conversely, if capacitance
control circuit 410_Z is deactivated, pass gate control
circuit 420_Z switches pass gate 430_Z to a non-conductive
state, which isolates clock distribution network 230
capacitor 440_Z. Thus, in the deactivated state, capacitance
control circuit 410_0 does not add significant capacitance to
clock distribution network 230.

[0038]   In one embodiment of the present invention,
capacitance C_Z of each capacitor 440_Z is equal to a base
capacitance C_B. Thus, capacitance control circuits 410_0 to
410_X can provide a tunable capacitance C_tune between 0 and
X * C_B. In another embodiment of the present invention,

each capacitor 440_Z has a capacitance C_Z equal to base capacitance C_B multiplied by two to the power of Z (see equation (7)).

$$C\_Z = C\_B * 2^Z \qquad\qquad (7)$$

[0039]   For this embodiment, capacitance control circuits 410_0 to 410_X can provide a tunable capacitance C_tune between 0 and C_B * $(2^{(X+1)} -1)$. The value of base capacitance C_B is determined by the frequency range and the capacitance range of the integrated circuit.

[0040]   Figure 5 is a schematic diagram of a tunable clock distribution system 500 of an alternative embodiment of the present invention. The tunable clock distribution system 500 receives as input system clock S_CLK and outputs L_CLK to clock distribution network 230. Tunable clock distribution system 500 is part of an FPGA with configuration memory cells such as 510, 512, 514, and 516, that are set (or reset) to 1 or 0, when the FPGA is configured or reconfigured. Tunable clock distribution system 500 has a set of one or more substantially identical blocks, e.g., blocks 506, 507, and 508.

[0041]   Block 506 has input S-CLK, inductor L1, NMOS transistor T1, NMOS transistor T2, capacitor C1, configuration memory cells 510 and 512, and output node 522. Input S-CLK is connected to the inductor L1 which is connected in parallel with bypass NMOS transistor T1. The gate of transistor T1 is connected to configuration memory cell 510, which determines whether inductor L1 is bypassed or not. The inductor L1 is also connected to transistor T2 and output node 522. Transistor T2 is connected in series to capacitor C1, which in turn is connected to ground. The gate of transistor T2 is connected to configuration memory cell 512, which determines whether capacitor C1 is connected to output node 522 or not. The output node 522 of block 506 is the input to block 507. Block 507 has inductor L2, NMOS transistor T3, NMOS transistor T4, capacitor C2,

configuration memory cells 514 and 516, and output node 524.
The components in block 507 are connected similarly to those
in block 506.

[0042]   As can be seen from Figure 5 setting configuration
memory cells 510 to 0, e.g., ground, and 512 to 1, e.g., Vcc,
inductance L1 and capacitance C1 is added from block 506 to
clock distribution network 230. Other combinations of
configuration memory cells 510 and 512, may add inductance L1
only, capacitance C1 only, or neither capacitance or
inductance from block 506 to clock distribution network 230.
Since block 507 is series connected with block 506 by
appropriately setting or resetting configuration memory cells
514 and 516, additional inductance L2 and/or capacitance C2
may be added to that of block 506. In should be understood
to those of ordinary skill in the arts that blocks 506, 507,
and 508 may be connected in series, parallel, or a
combination of both and that the number of blocks may be one
or more (Figure 5 only shows an illustrative number and
configuration for one embodiment).

[0043]   In the various embodiments of the present
invention, novel structures have been described for tuning
the resonant frequency F_r of a tunable clock distribution
system. The tunable clock distribution circuit of
embodiments of the present invention can reduce the power
dissipation of a clock distribution network. Specifically,
the resonant frequency F_r of the tunable clock distribution
system is tuned by adding a tunable inductance L_tune and a
tunable capacitance C_tune to the clock distribution network.
By controlling both tunable capacitance C_tune and tunable
inductance L_tune, resonant frequency F_r can be tuned to
equal clock frequency F_clk of system clock signal S_CLK.
Matching resonant frequency F_r with clock frequency F_clk
minimizes the power dissipation of the clock distribution
network.

[0044]   In an alternative embodiment of the present
invention the tunable clock distribution system 200 of Figure

2, provides an adjustable inductance, an adjustable
capacitance or any combination thereof, that can vary the
resonance frequency of a clock distribution network. While
it is desirable to substantially match the resonance
frequency to frequency of the clock which is input into the
tunable clock distribution system 200, in this alternative
embodiment the adjustable inductance, the adjustable
capacitance or any combination thereof, is adjusted so that
the resonance frequency is a function of the frequency of the
input clock. Where an FPGA is used the adjustable inductance
and the adjustable capacitance are programmable (i.e., their
inductance and capacitance may be changed by adding/removing
programmable inductive and capacitive elements, respectively)
by programming the configuration memory of the FPGA.

[0045]   The various embodiments of the structures and
methods of this invention that are described above are
illustrative only of the principles of this invention and are
not intended to limit the scope of the invention to the
particular embodiments described. For example, in view of
this disclosure those skilled in the art can define other
tunable clock distribution circuits, inductance control
circuits, capacitance control circuits, pass gate control
circuits, controllable inductance circuits, and so forth, and
use these alternative features to create a method, circuit,
or system according to the principles of this invention.
Thus, the invention is limited only by the following claims.